Climate Change and Arbovirus Disease Transmission

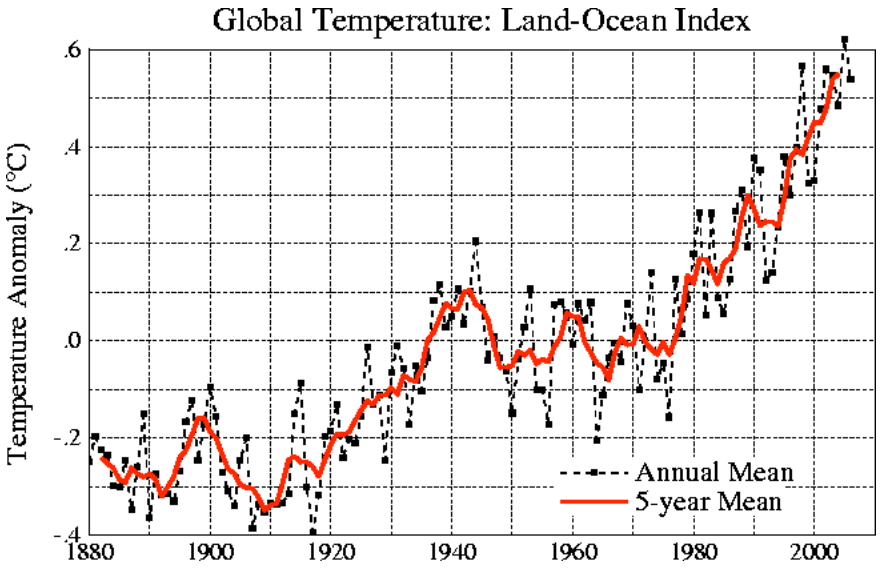


Image: NASA

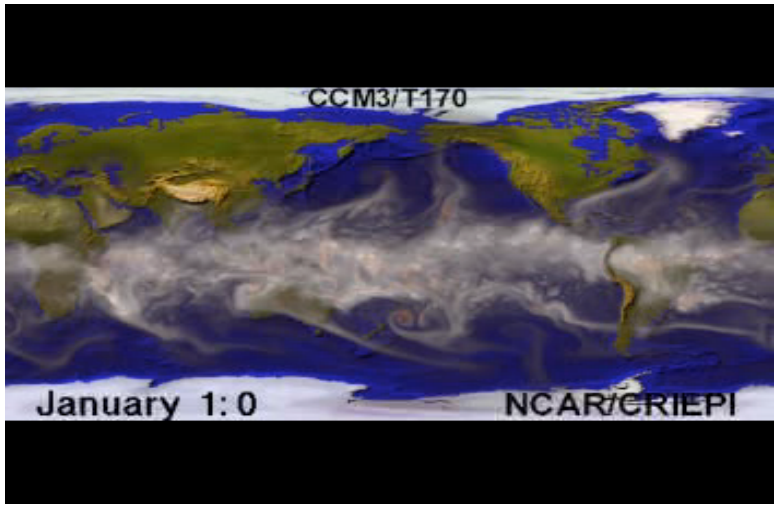
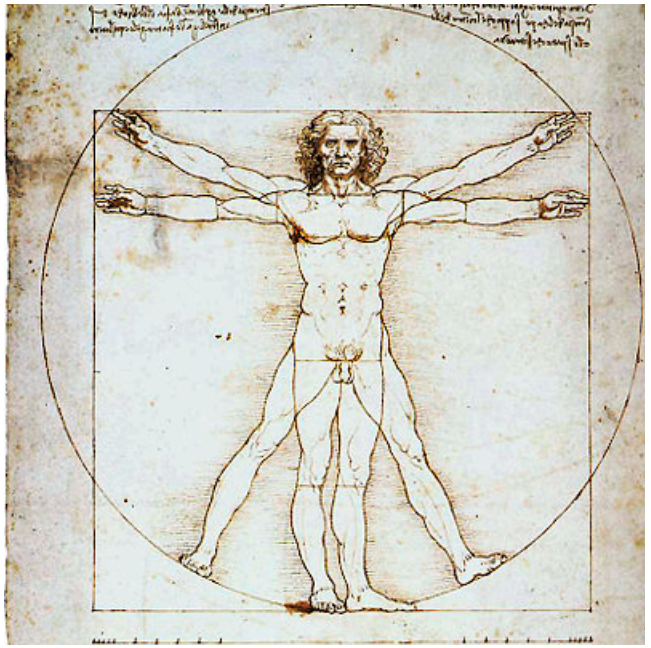


Image: NOAA

Jeffrey Shaman
College of Oceanic and Atmospheric Sciences
Oregon State University

February 20, 2009



Thucydides

Royal Ontario Museum
Photo: Public Domain

History of the Peloponnesian War
Book VII
The destruction of the Athenian expedition at Syracuse in 413 BC

After a particularly devastating battle 'the Athenian generals consulted upon the disaster which had happened, and upon the general weakness of the army. They saw themselves unsuccessful in their enterprises, and the soldiers disgusted with their stay; disease being rife among them owing to its being the sickly season of the year, and to the marshy and unhealthy nature of the spot in which they were encamped'.

Bath

The contrasts of the pestilence of reeking, noxious marsh airs and putrid stagnant waters and the salubrity of fragrant country air and fresh, running mountain waters were recognized

However, misunderstanding remained about how and why these differences manifested as noisy patterns of disease and health

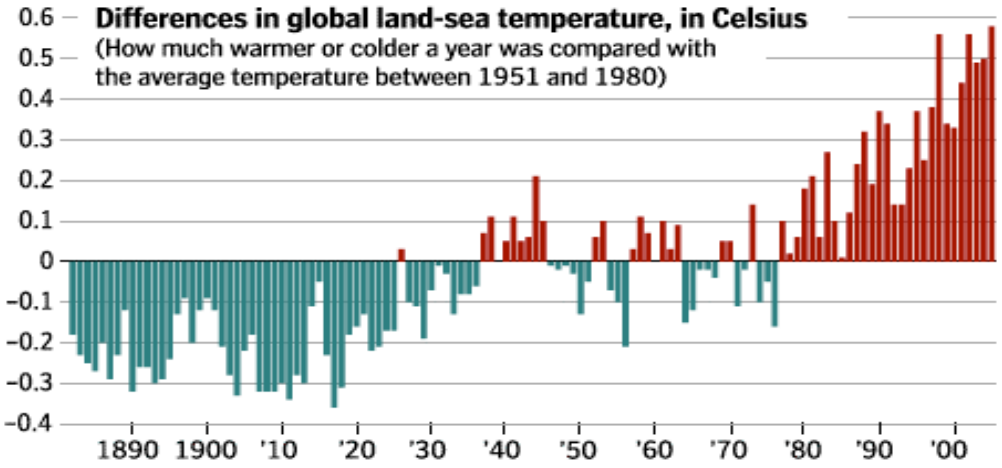
Medical Geography

Snow, J. *On the Mode of Communication of Cholera.* John Churchill, New Burlington Street, London, England, 1855

Dr. John Snow and Cholera

- Mapped cholera incidence in London during 1854 outbreak -- provided evidence for its transmission by water.
- Showed that most cases during an 1854 outbreak in London surrounded the water pump at Broad and Cambridge streets.
- Showed that locals who only drank beer were fine.
- The nearby prison had its own well and only 5 cases (535 prisoners).
- Even those who lived far away from the pump had taken waters from it prior to falling ill
- A sewer lay near the well (22 feet below ground)

Increasing Attention on the Effects of Climate Variability and Global Warming on Human Health



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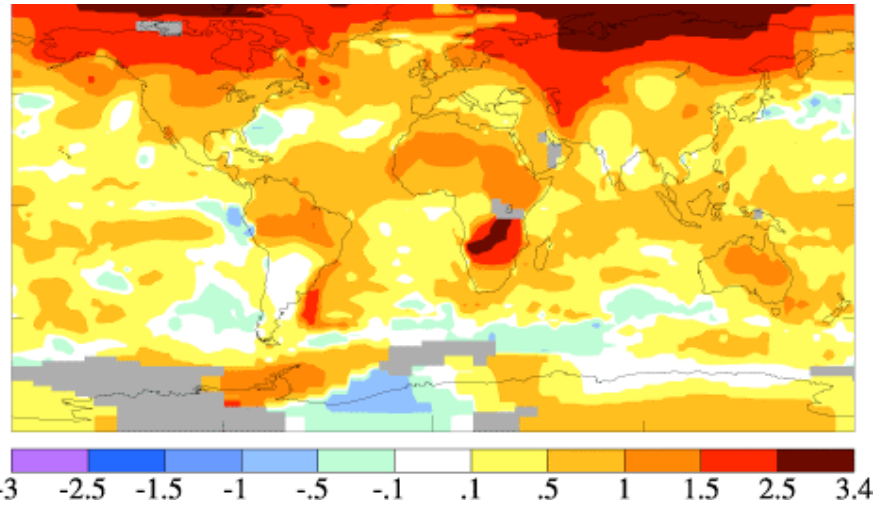

Image: NASA

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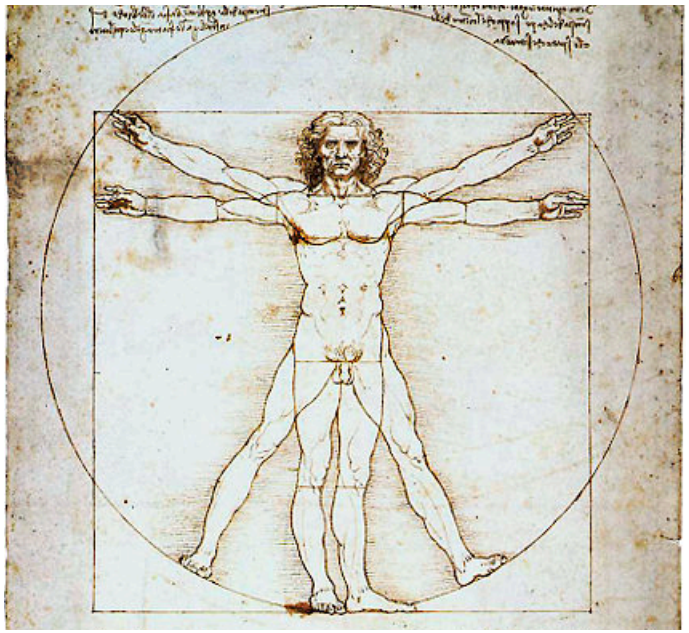

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The Broadest Terms

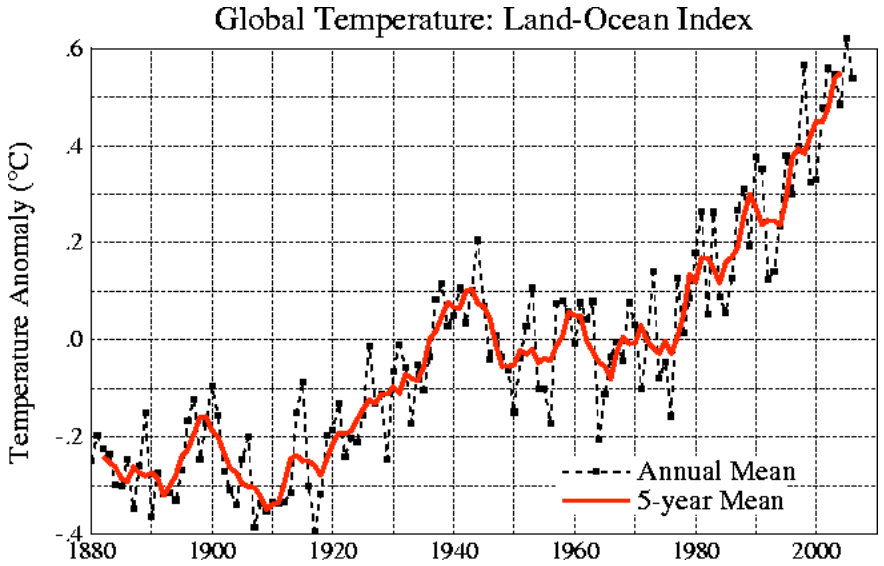
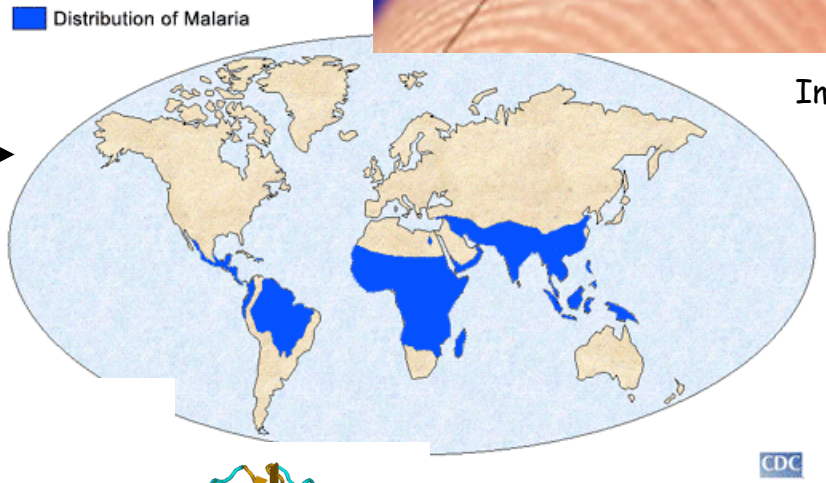


Image: NASA

Image: CDC



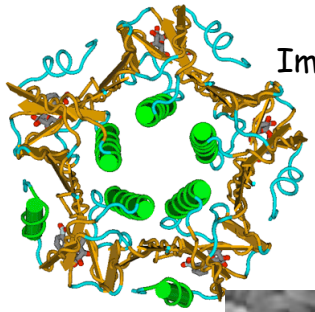


Image: NIH

El Niño Anomaly Index

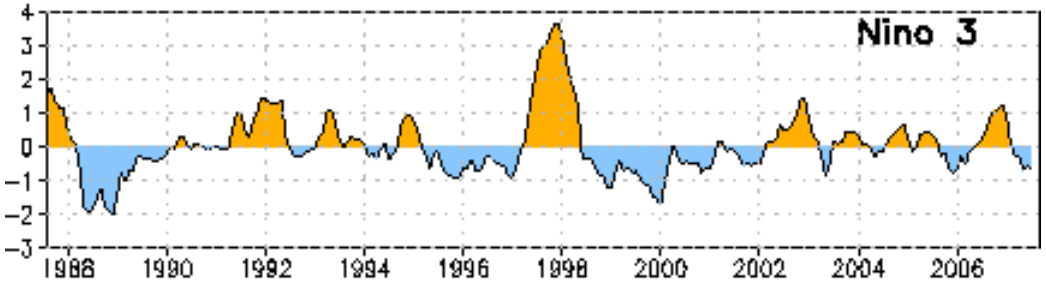


Image: NOAA

Image: Dartmouth EMF

Global Warming and Malaria

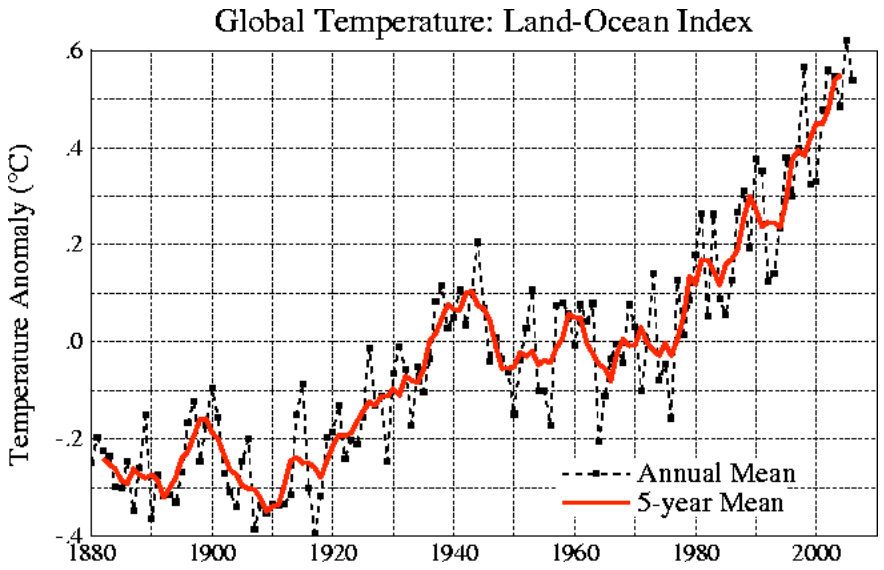


Image: NASA

How does climate variability affect malaria transmission?

- Local Rainfall
- Local Temperature
- Local Humidity
- The Local Environment

??

Other Factors:

- Genetics
- Medical and Public Health Infrastructure
- Land Use
- Socio-economic Conditions
- Travel and Trade
- Human Conflict

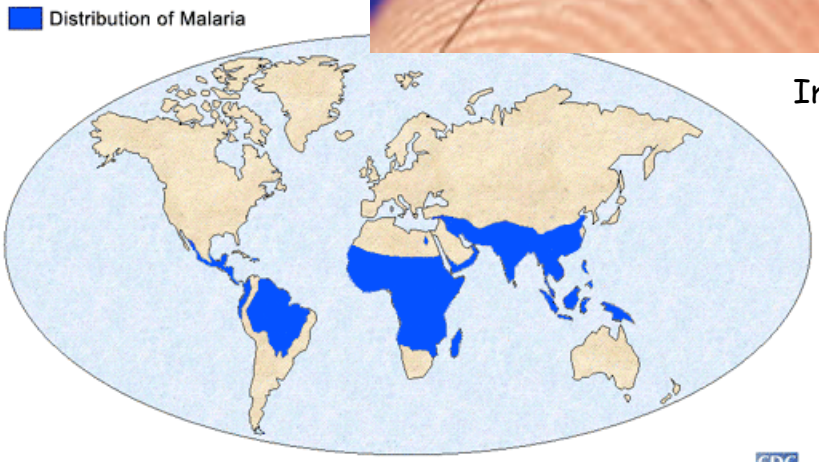


Image: CDC

An Individual Basis?

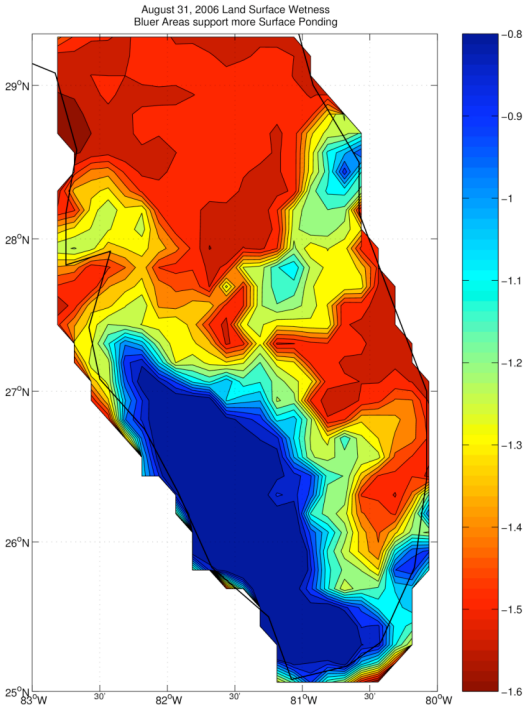
Medicine	Public Health
Focus on Individual	Focus on Population
Personal Service	Public Service
Emphasis on Diagnosis and Treatment	Emphasis on Prevention and Community Health

An Integrated Effect

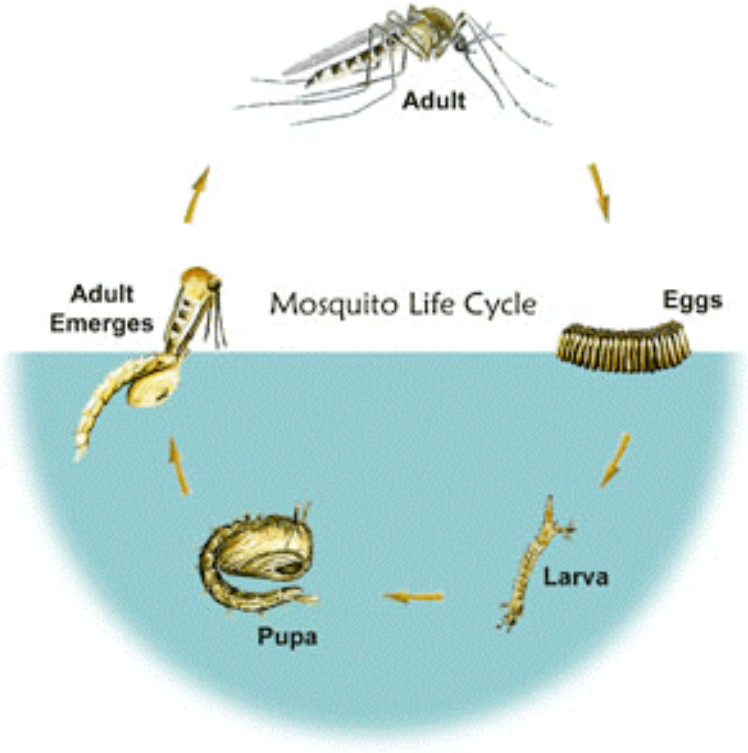
The public health response to a changing environment may manifest at regional or global scales, but often it is the sum of local processes and interactions

Modeling and Forecasting Mosquito-Borne Disease Transmission

Use hydrologic simulations to explore *local* empirical relationships between modeled land surface wetness and mosquito abundances and the transmission of mosquito-borne pathogens.

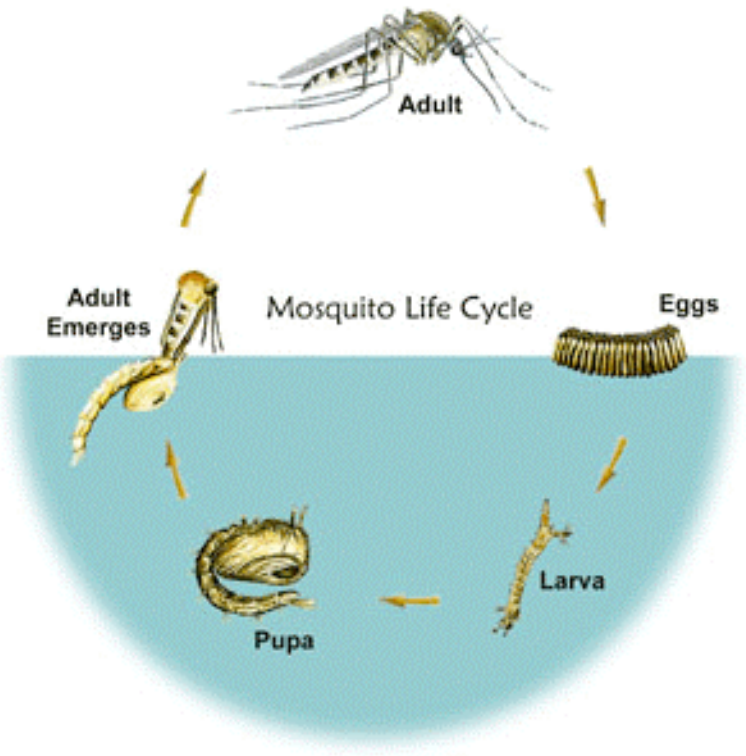


The first 3 stages of the mosquito life cycle (egg, larvae, pupae) are aquatic. Mosquitoes depend critically on the availability of water.



Attempt to identify the mechanisms by which weather and climate affect such disease systems, use these links to develop disease monitoring

Rainfall has two principal influences on the mosquito life cycle



1) The increased near-surface humidity associated with rainfall affects mosquito flight activity and host-seeking behavior

2) Rainfall can alter the abundance and type of aquatic habitats available to the mosquito for the deposition of eggs (oviposition) and the subsequent development of the immature stages.

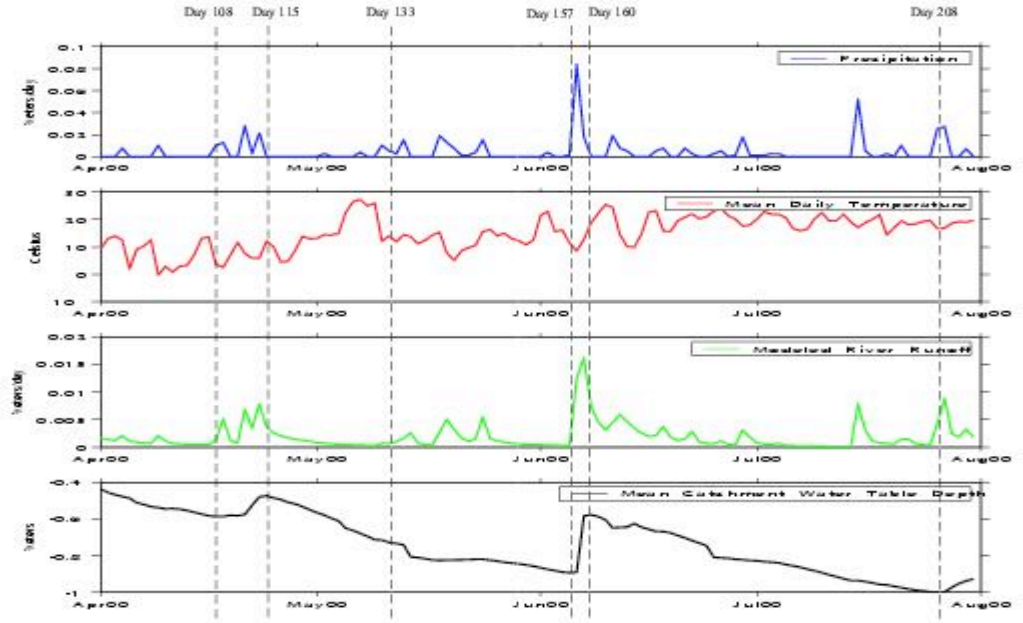
Why Model Hydrology?

To first order, variations in water table depth (WTD) determine where and when water accumulates at the land surface

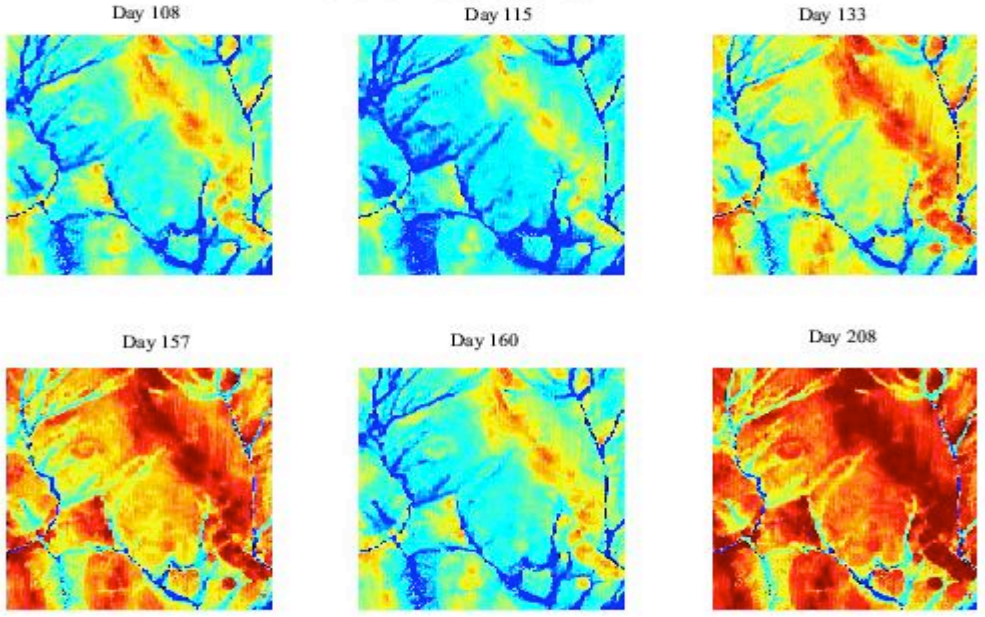
Precipitation is not the only determinant of WTD

Evapotranspiration and rates of runoff generation must also be constrained if WTD is to be accurately modeled

Figure 1
Time Series of Precipitation, Temperature, Modeled River Runoff and Modeled Mean Water Table Depth
Black Rock Forest, Orange County, New York, USA; April 1 - July 31, 2000



Modeled Surface Wetness for Selected Julian Days; Blue Areas are Wettest
10 Meter Pixels; Total Area 4 km^2



Disease system dynamics are highly variable and ultimately we want to operationally monitor and forecast these diseases

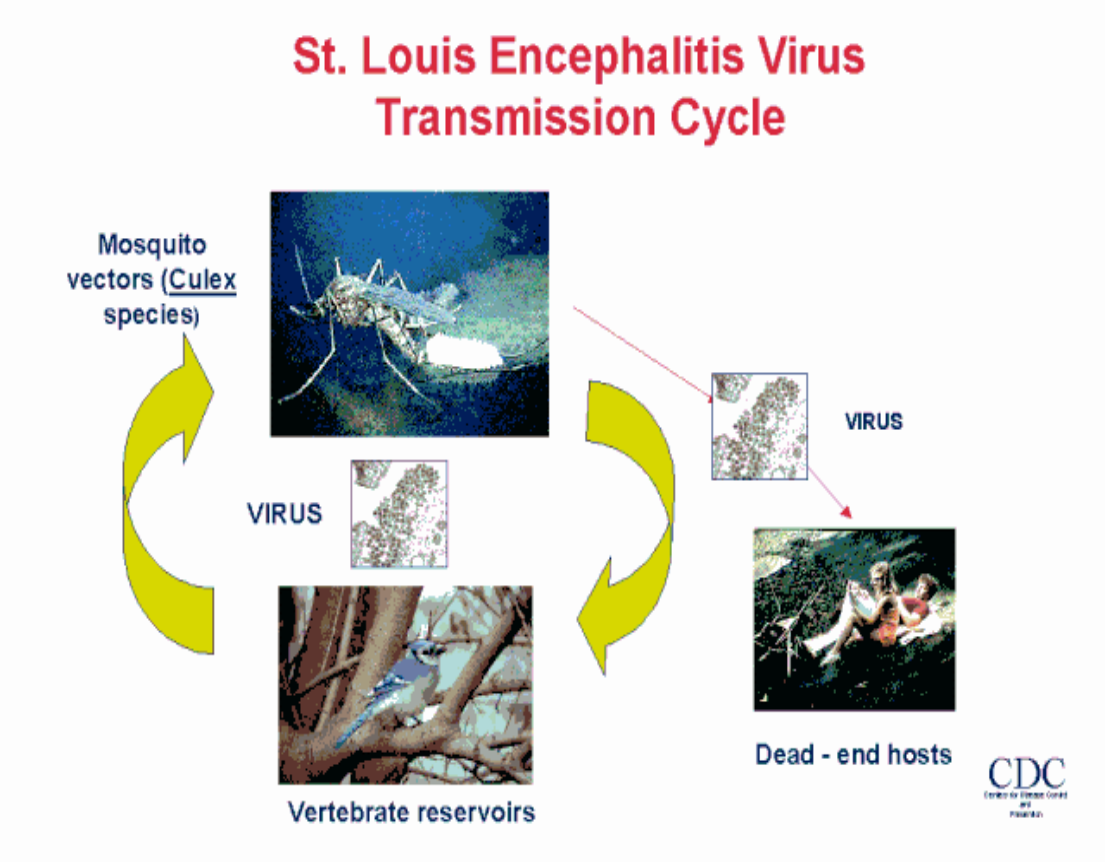
Examining Specific Pathogens: St. Louis Encephalitis virus and West Nile virus

In a Specific Area: South Florida

Where it has a Specific Vector: *Culex nigripalpus*

St. Louis Encephalitis

- Mosquito-born Disease
- Flavivirus similar to West Nile virus and Japanese Encephalitis virus
- Up to 3000 Clinical Cases per year (Meningitis and Encephalitis)
- Majority of Cases are Subclinical or Mild
- No Vaccine Available



Culex nigripalpus

- Ubiquitous Breeder (acid swamps, lime sinks, lakes, temporary pools, epiphytes)
- Feeds on mammals and birds
- Principal vector of SLE in Florida
- Rests during day among dense vegetation

The 4 Phases of the Florida SLE Virus Transmission Cycle

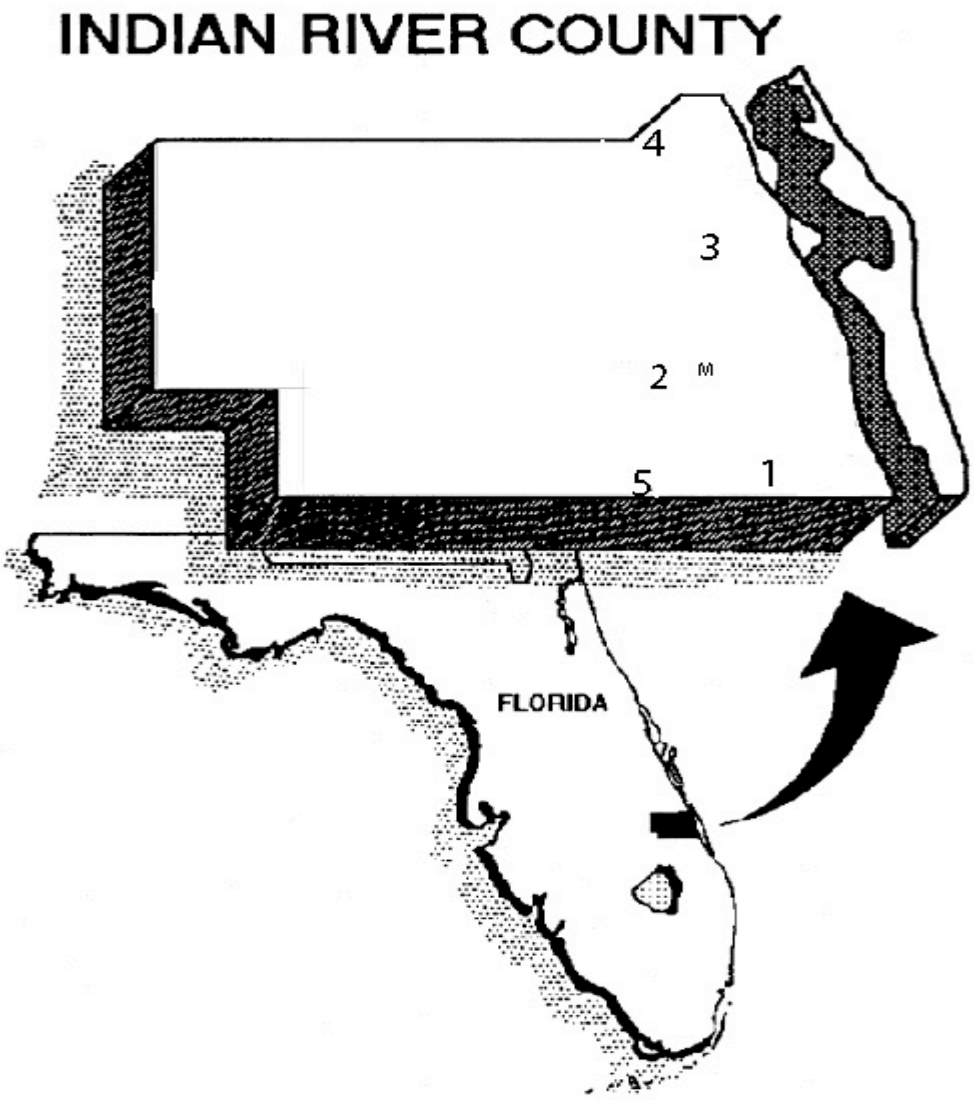
January – March: Maintenance
April – June: Amplification
July – September: Early Transmission
October – December: Late Transmission

Day and Curtis, 1993

Amplification involves the epizootic cycling of SLE virus between mosquito vectors and avian amplification hosts. It is necessary to achieve mosquito infection rates sufficient to cause human epidemics.

McLean and Bowen, 1980

1990 Florida SLE Epidemic



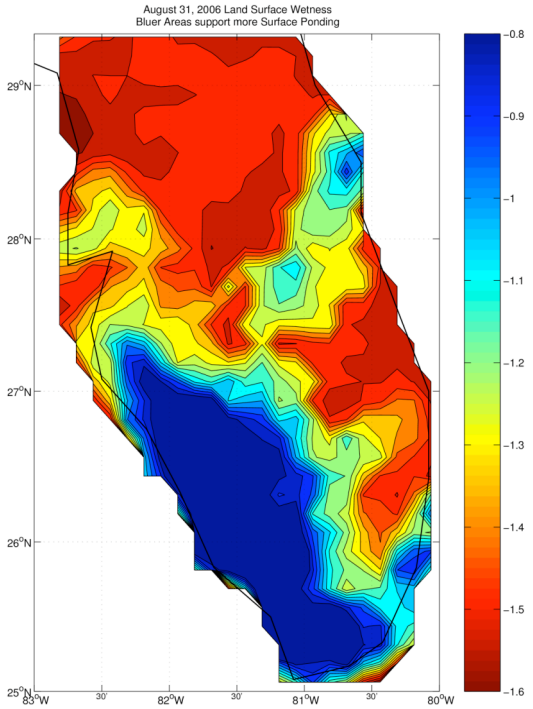
226 clinical cases of SLE were reported in Florida

Indian River County was the Epicenter

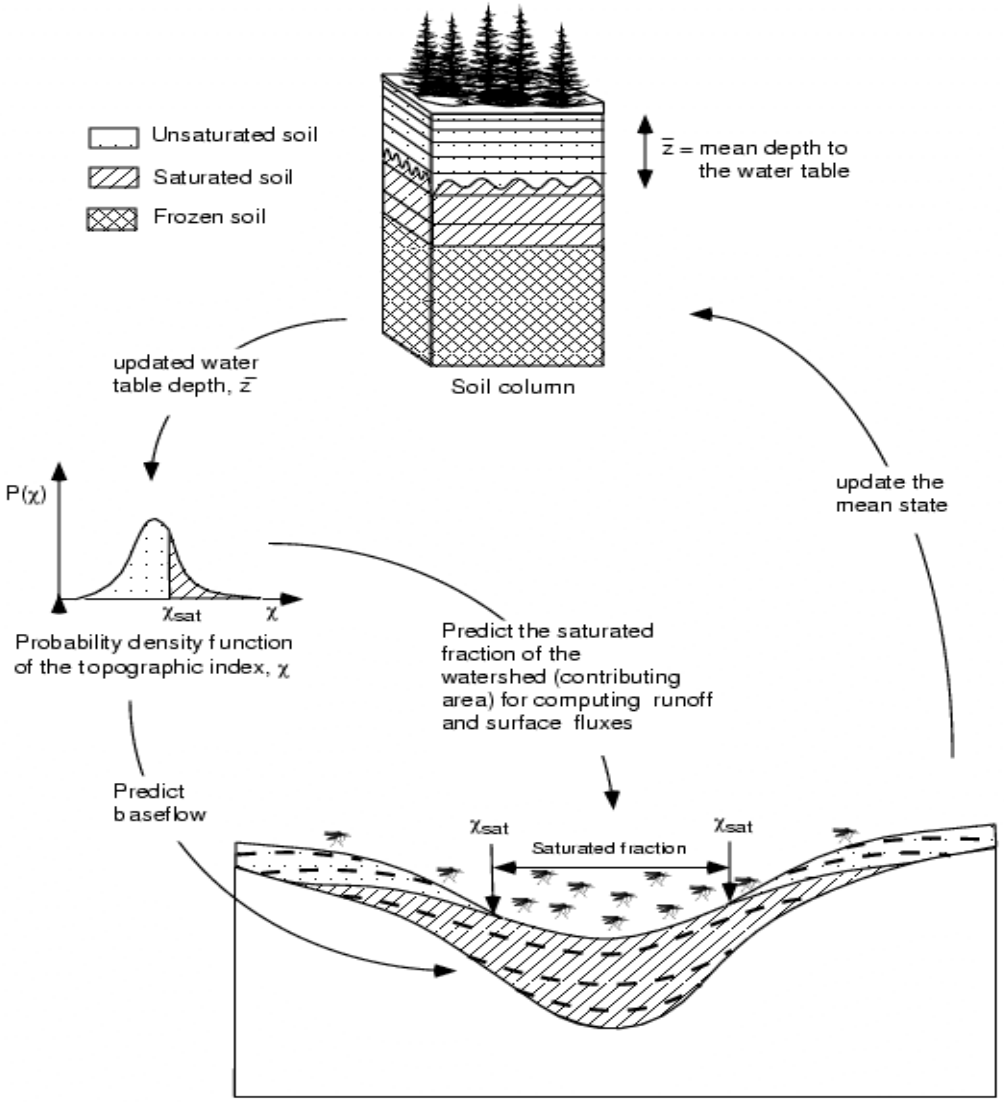
Sentinel Chicken Transmission Data (Numbers) and Mosquito Resting Abundance Data (M) were Collected 1986-1991.

Florida Specifics

- Subtropical climate
- Drought occurs seasonally during spring
- Summer is the wet season
- Surface water heavily managed
- Landscape fragmented



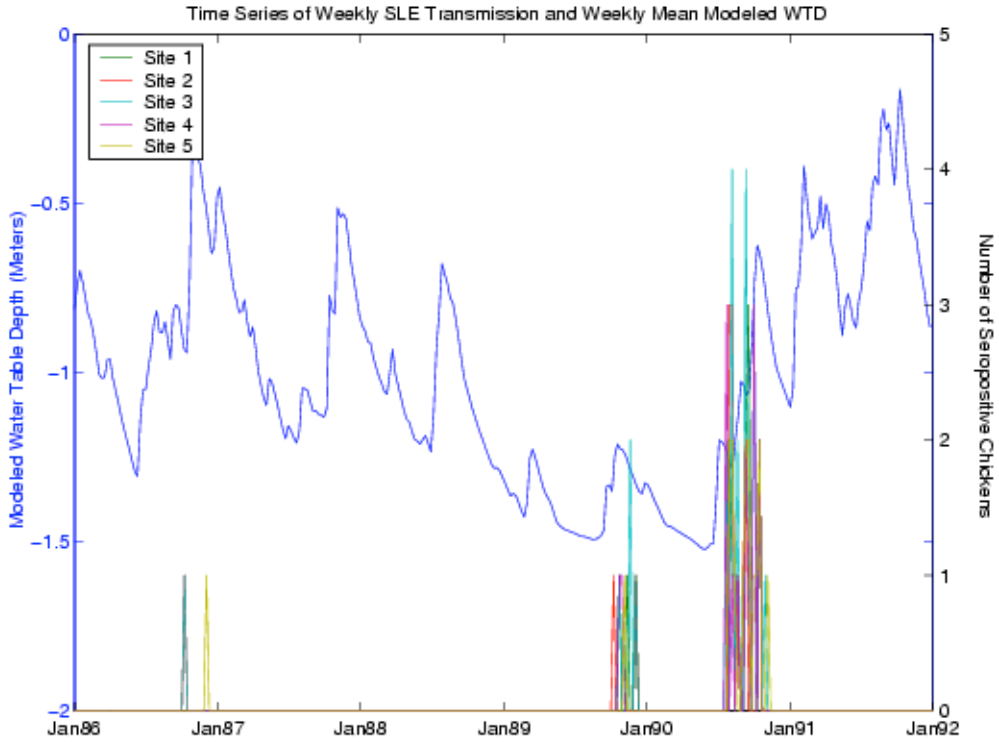
Modeled the Hydrology
Vero Beach, Indian River County



TOPMODEL-based Hydrology (TBH) Model

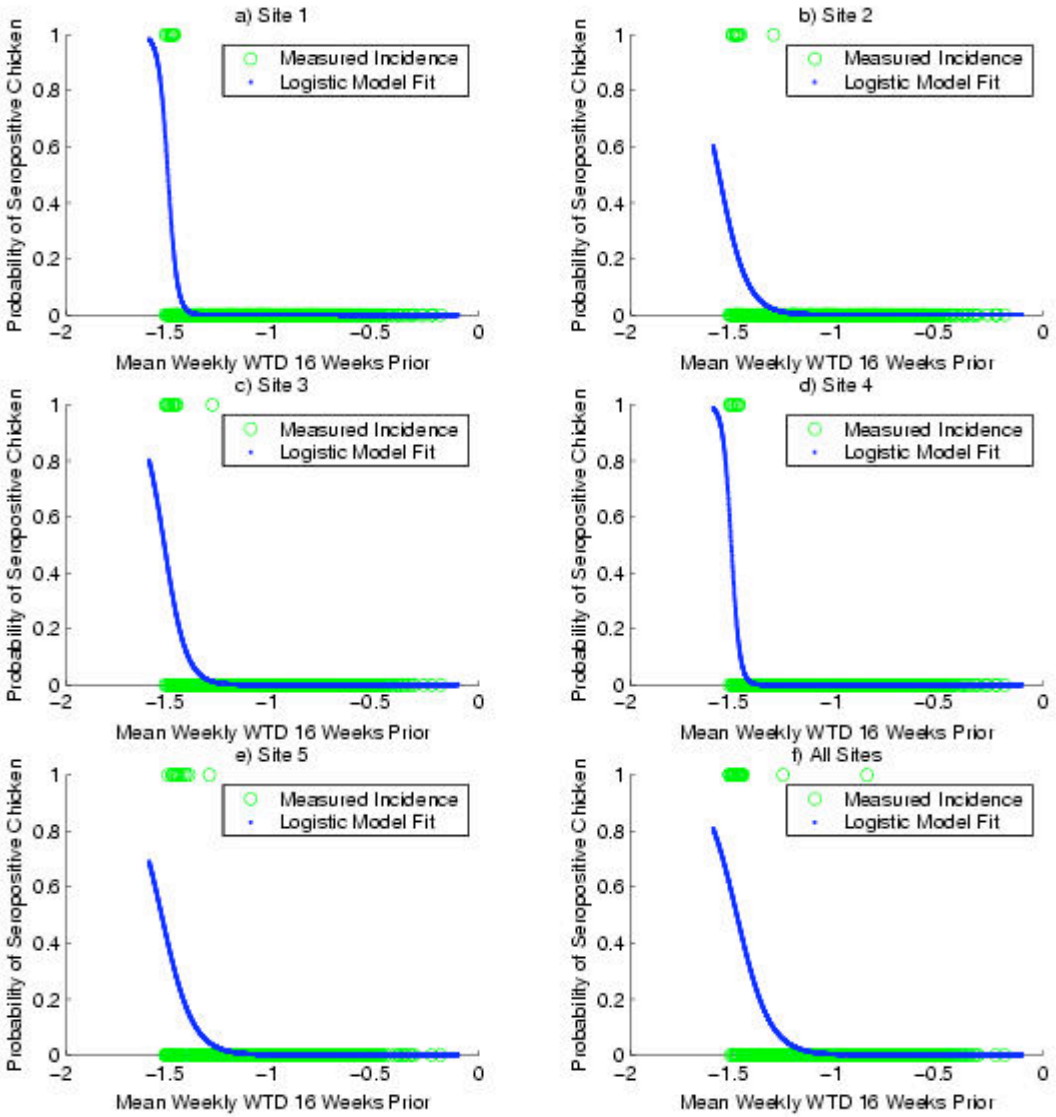
Produces a time series of mean area Water Table Depth (WTD) – a measure of drought and larval habitat availability

Time Series of Weekly Sentinel Chicken Seroconversion



- Three Instances of SLE transmission ('86,'89,'90)
- All 3 Episodes Occurred During a Period of Wetting Following a Drought

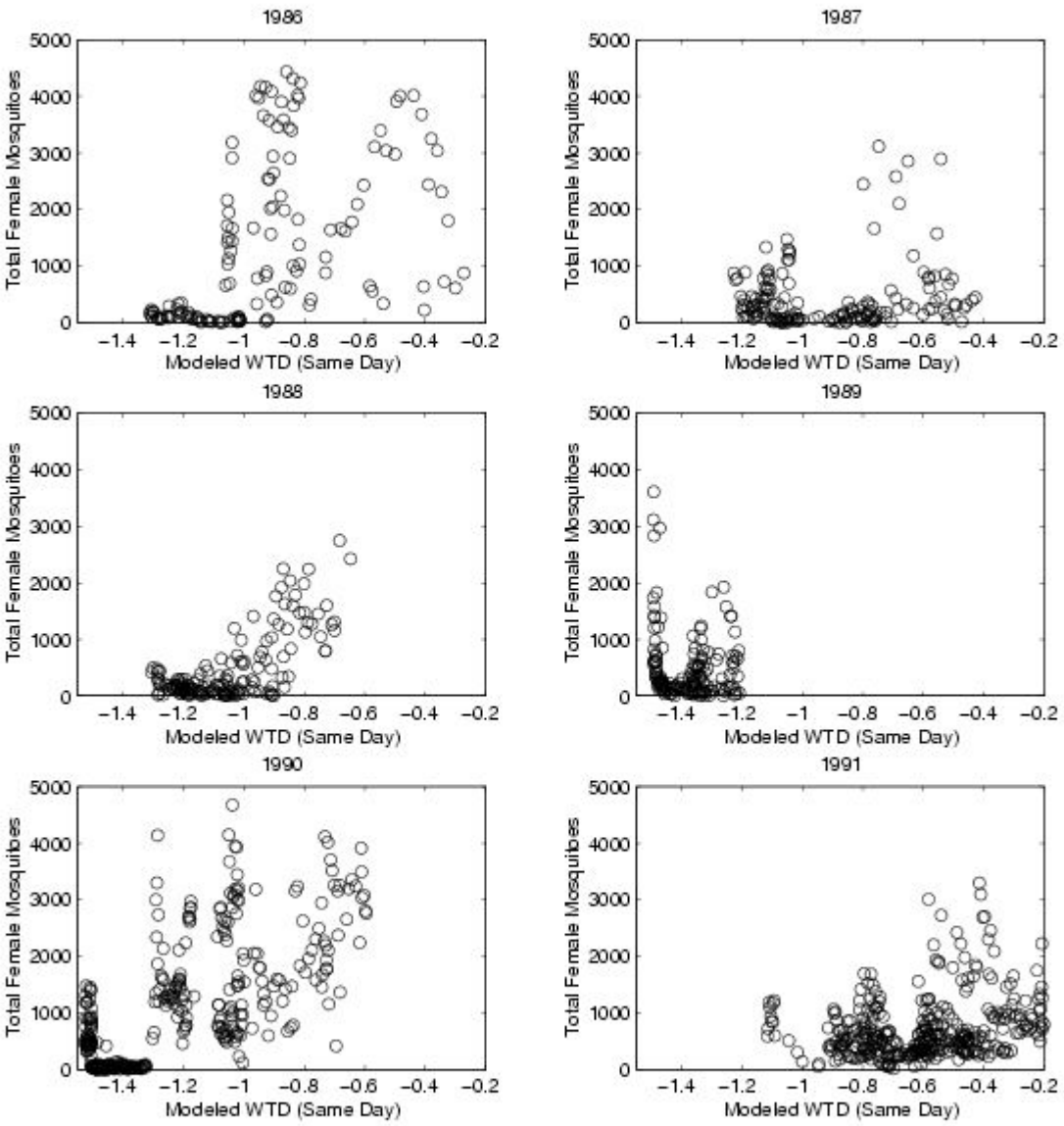
Employed Logistic Regression



$$\log(p/(1-p)) = X * \beta$$

Found consistent, robust relationship in which the probability of SLE virus transmission is statistically significantly associated with drought 4 months prior and wetting 0.5-1 month prior

Basis of the Relationship



At driest modeled conditions, during 1989 and 1990, there is an increase in mosquito abundance at the hammock resting site

2 Interpretations: Mosquito abundance increased during drought, or mosquitoes congregate in the hammocks during drought

Timing of Droughts Coincides with Nesting Season

Nesting Birds Use the Same Hammock Environments as *Cx. nigripalpus*

Amplification

Conclusion/Hypothesis

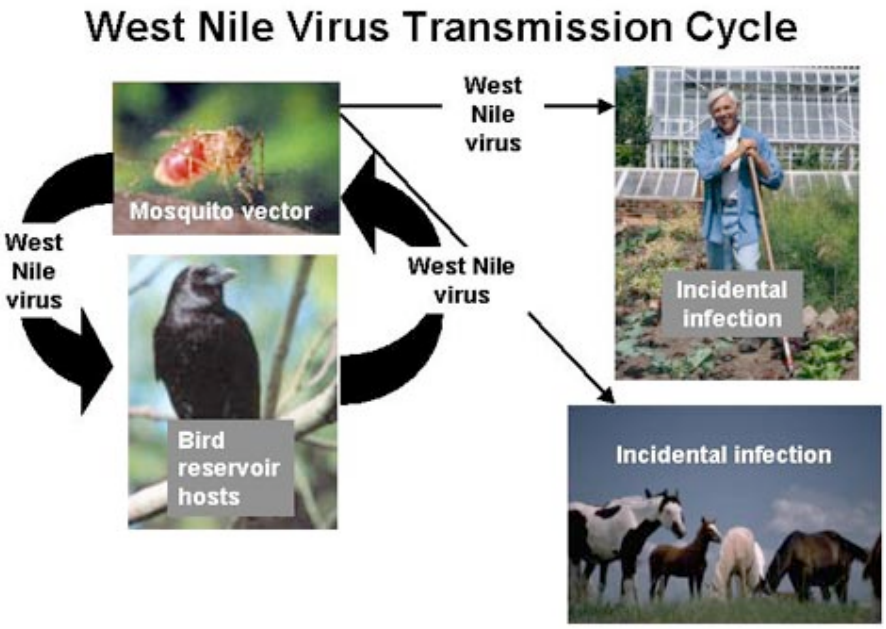
- Spring drought restricts *Cx. nigripalpus* activity to select refuges (hammocks) where nestling, juvenile and adult birds are found

- Forced cohabitation of the vector and avian host permits rapid epizootic amplification of the SLE virus

- When the drought ends, the infected mosquitoes and birds disperse from the hammocks and initiate the early transmission phase of the Florida SLE cycle

We have documented the same association throughout South Florida of spring drought and summer wetting with:

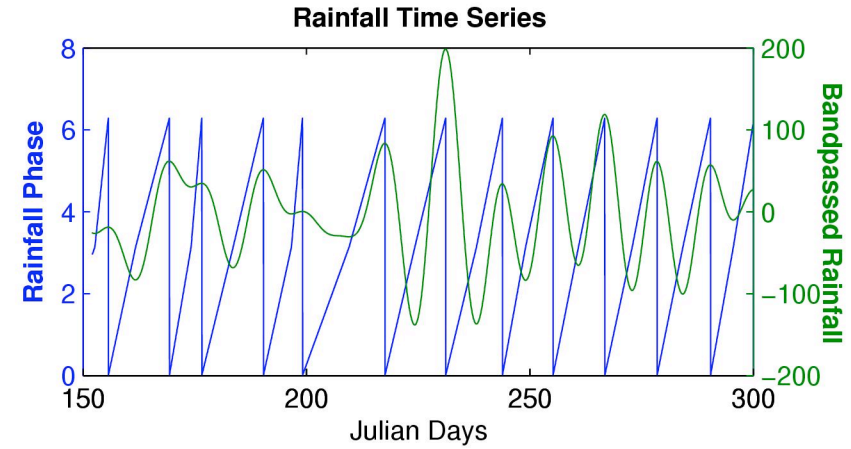
1) Transmission of SLEV to wild birds
2) Epidemic SLEV transmission to sentinel chickens
3) Human cases of SLEV throughout South Florida
4) Human cases of WNV throughout South Florida

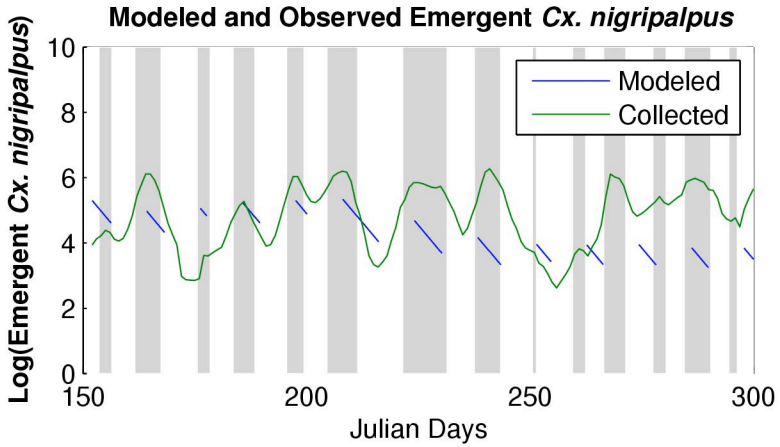


Data span 1979-present

How summer wetting manifests affects transmission

The frequency at which major rain events occur is important





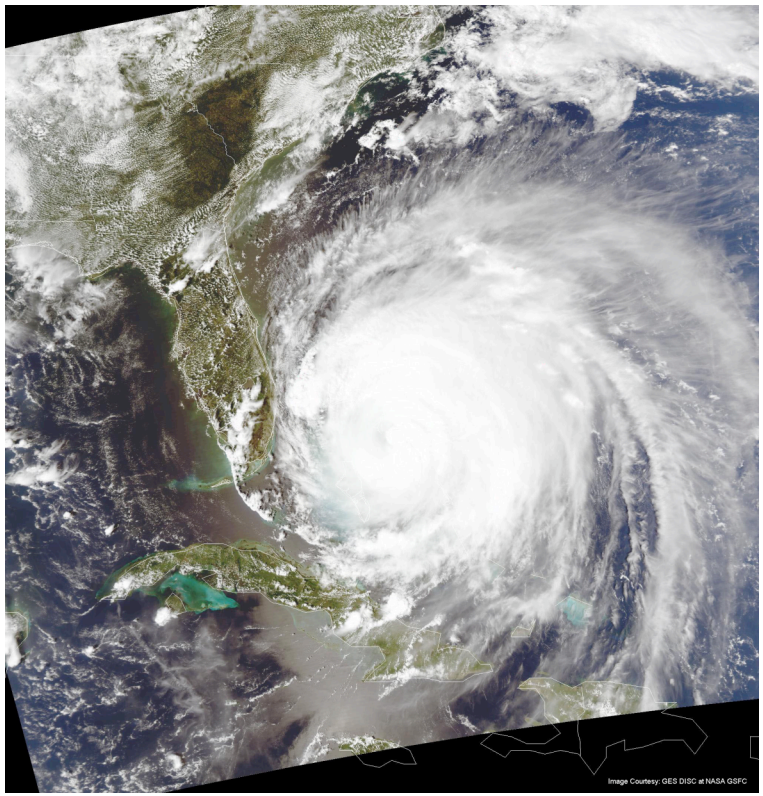
Model the mosquito reproductive cycle as a forced phase oscillator

$$\frac{d\phi}{dt} = \omega_m + k\,sin(\phi - \theta)$$

$$\frac{d\theta}{dt} = \omega_r$$

ϕ is the phase of the mosquito reproductive cycle
θ is the phase of the rainfall cycle
ω_m is the natural frequency of mosquito reproductive cycle
ω_r is the frequency of rainfall events
k is the coupling coefficient

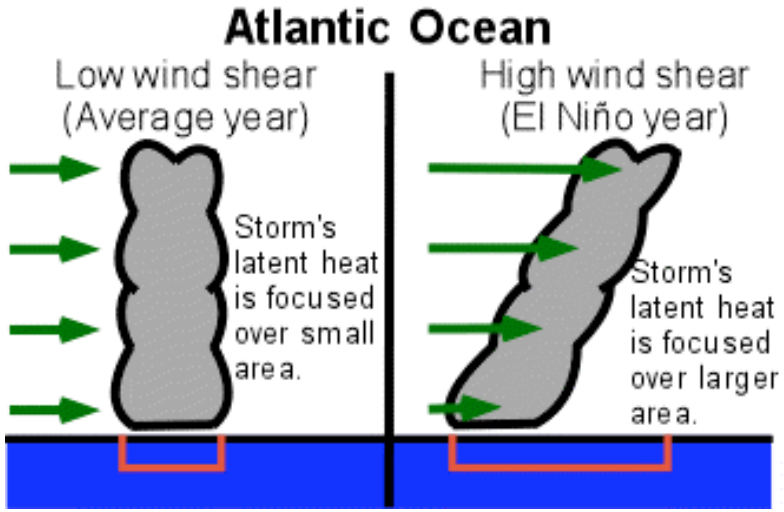
How summer wetting manifests affects transmission



El Niño and Atlantic Hurricanes

	Atlantic	
	Average	El Niño Avg.
Named storms	9.4	7.1
Hurricanes	5.8	4.0
Intense Hurricanes	2.5	1.5

Extreme events, such as hurricanes, are disruptive

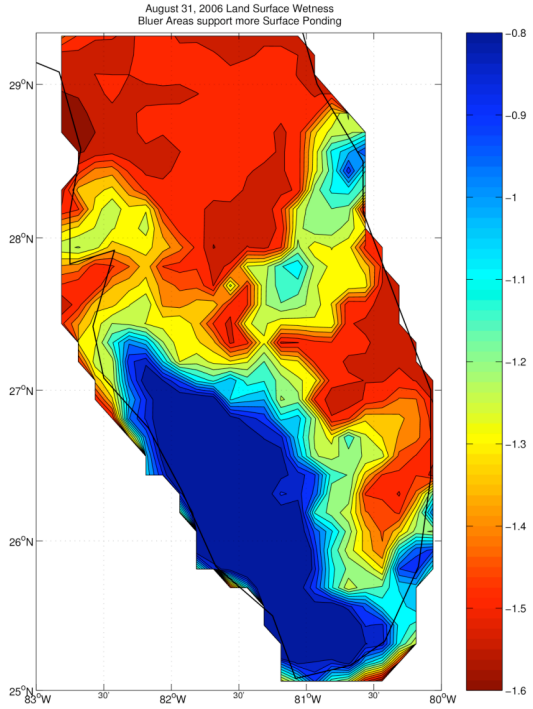


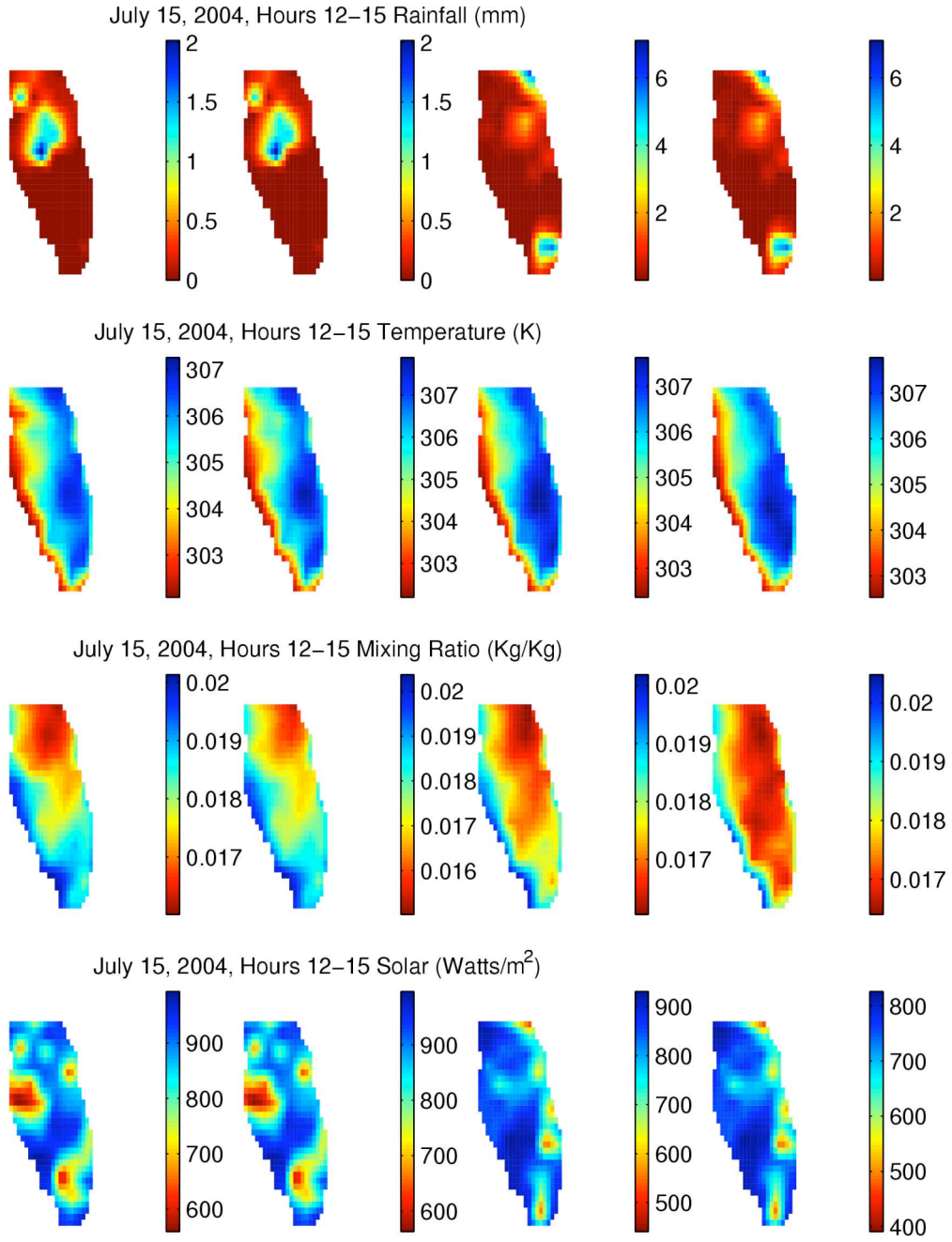
Image/Text/Data from the University of Illinois WW2010 Project

Have a stationary, predictive empirical relationship with a built-in 1-4 month lead

- Found May drought is particularly important
- Human cases typically don't appear until July
- Real-time hydrological monitoring is itself predictive

We now use real-time NOAA/NASA National Land Data Assimilation System (NLDAS) Project data, which provides hourly surface conditions distributed at 0.125° resolution. This enables modeling of land surface conditions (i.e. drought and wetting) near the convective scale (~13km)





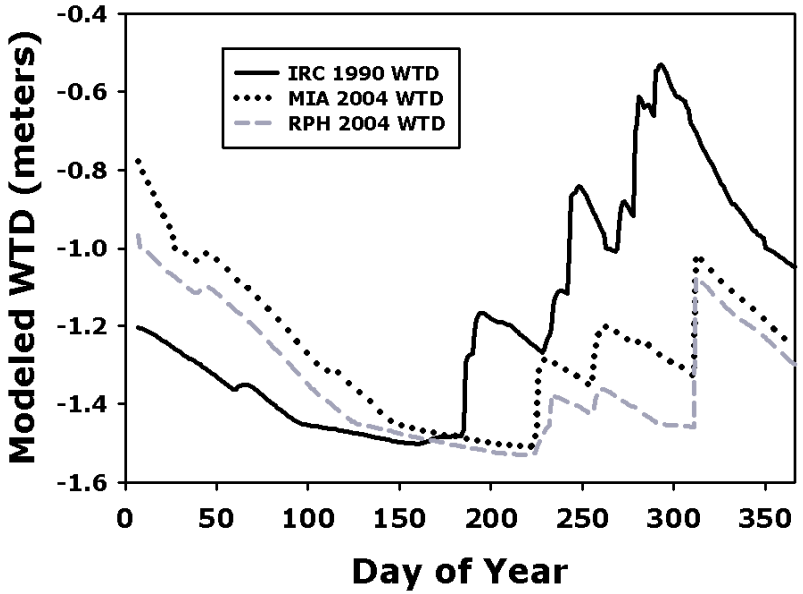
Operational Use

5 Bdrm,
4.5 Bth,
5344ft^2
$3m

Dade County was placed on Medical Alert for WNV on July 14, 2004.

The issuance of the Medical Alert was a joint decision by workers at the Florida Dept. of Health in Tallahassee and the Dade County Public Health Unit.

Frequent Public Service Announcements (TV, radio, and print) were used to warn residents in the effected area about the risk of WNV transmission.



Additional vector surveillance and vector control efforts with ground adulticide applications were focused in the Coconut Grove area.

5 Bdrm,
5 Bth,
4570ft^2
$2.35m

Translation of Scientific Findings

- Modeled wetness conditions empirically associated with WNV and SLEV transmission

- Operational Use of these findings requires the education of and collaboration with public health officials

- Drought-induced amplification may be necessary for high levels of SLEV/WNV transmission, but it is not by itself a sufficient condition for such an event

- Findings only provide likelihoods (probabilities)

Control Optimization

While it would be nice to show that the monitoring system anticipates the next big epidemic, it would be even better if real-time measures were taken in response to the modeled hydrology that averted an epidemic.

But how? Should there be heightened, targeted control of vector mosquitoes within hammocks in areas of spring drought?

Need for study to determine the most effective control response. Should be optimized for best control, as well as least cost and adverse environmental impacts.

Requires ecological models, cost-benefit analyses

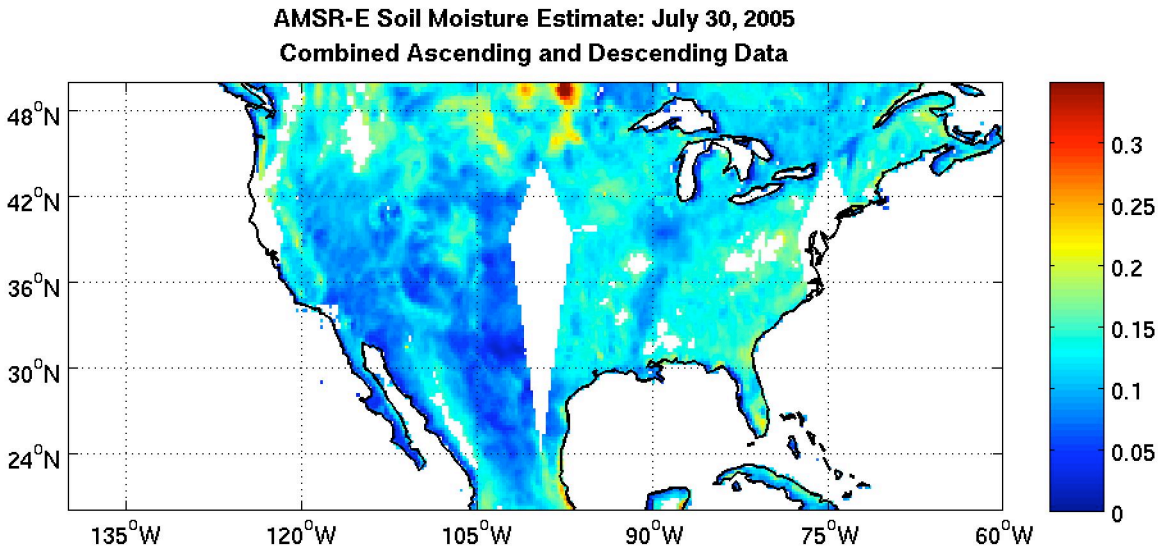
WNV Outside Florida

Have Begun to Look at Other Regions: Colorado and the Great Plains, the Pacific Northwest, New Mexico

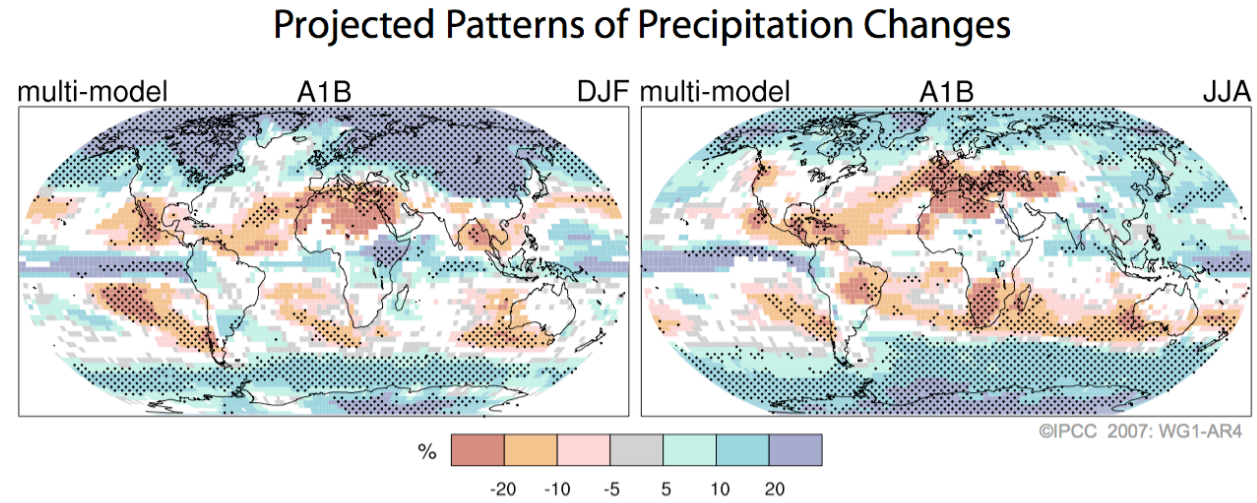
Each has a different hydrologic cycle and different land use patterns, vector species and avian host species, all of which affect WNV transmission dynamics

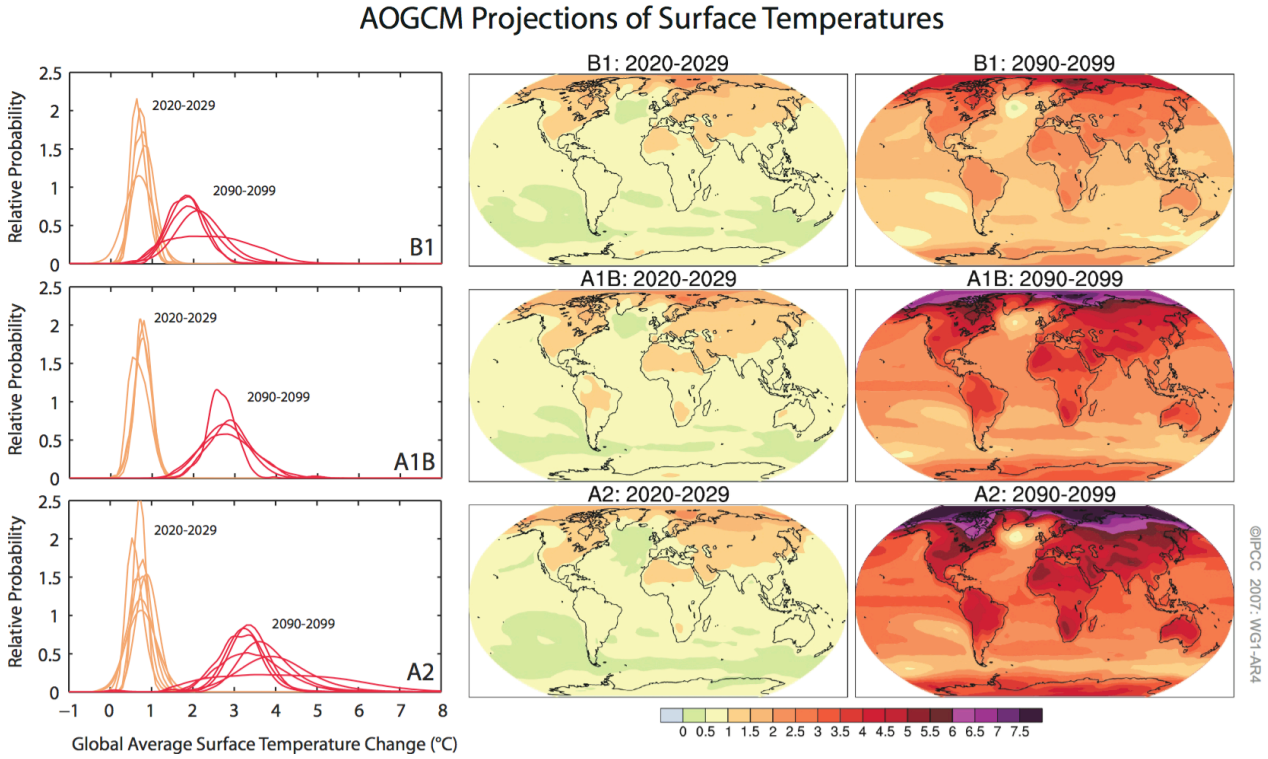
Using both model simulations and satellite observations of hydrology

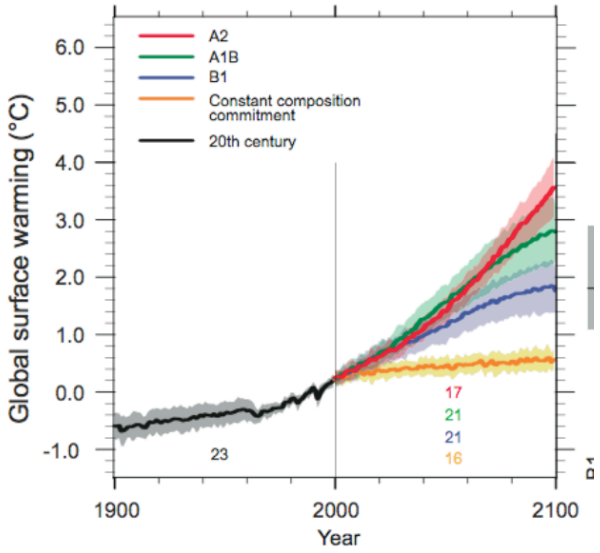
Ultimately may be able to monitor the entire country



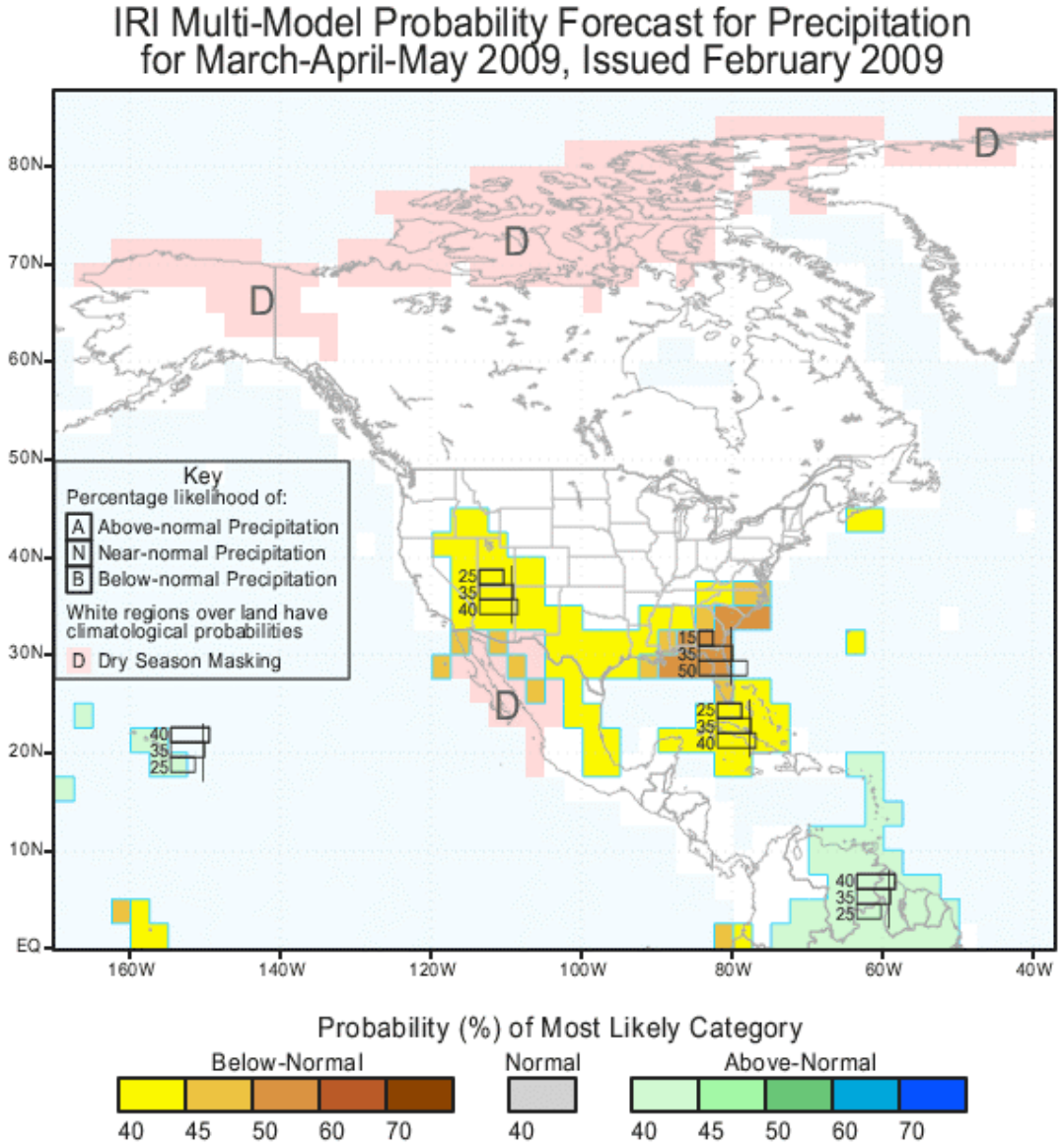
Coupling to IPCC forecasts







Seasonal Forecast



Issued as 3-Month Tercile Probabilities for Temperature and Precipitation

Skill of Forecast in south Florida

Rajagopalan et al., 2002

3 Tier Modeling System

1) Physical Model: Use a dynamic model to simulate the physical system. Attempted to match the scales of the physical model, biological system and operational application.

2) Empiric Model: Find a robust link between the abiotic and biotic. Found a robust relationship between modeled land surface wetness conditions and arbovirus transmission (cross validated).

3) Forecast Model: Use 1 and 2 to develop a forecast model. Developed an ensemble seasonal forecast of arbovirus transmission. Tested the skill of this model as a tool for operational forecast. This effort was another test of the empiric model's stationarity (the robustness of the findings).

Collaborators

Jonathan Day, University of Florida

Mark Cane, Columbia University

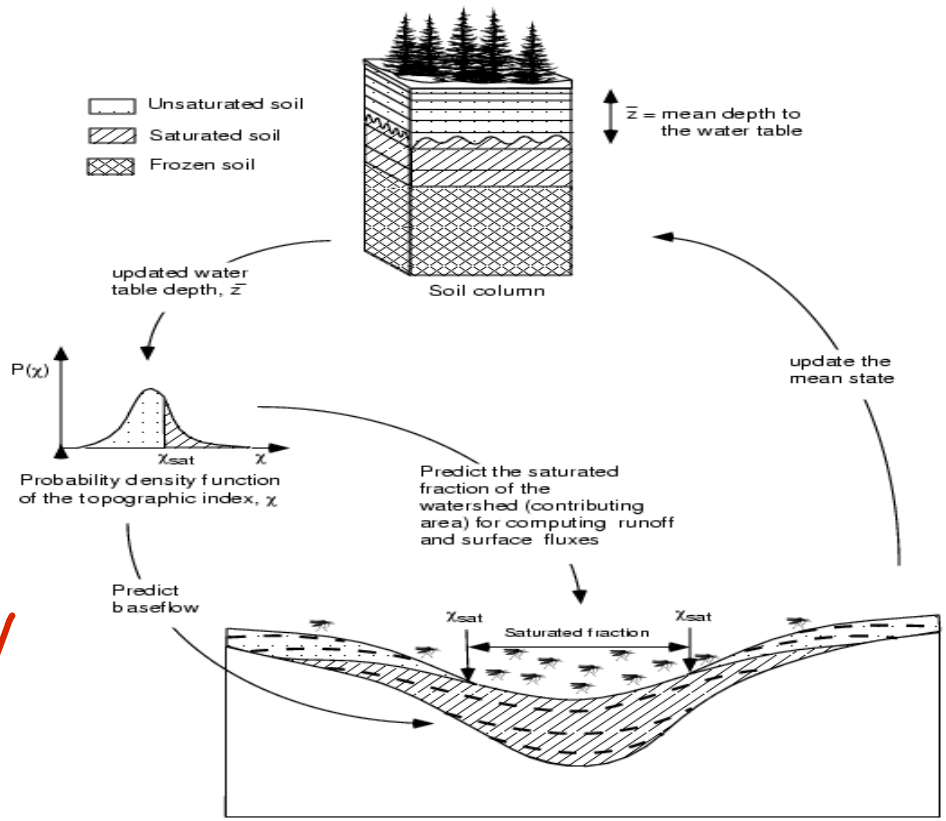
Marc Stieglitz, Georgia Institute of Technology

Stephen Zebiak, International Research Institute for Climate and Society

Nick Komar, Centers for Disease Control

While many 'non-hydrologic' factors affect transmission, these findings underscore a sequence of abiotic conditions that influence future arbovirus transmission rates

These results were established using hydrology model simulations of land surface wetness (drought) conditions, conditions which can be skillfully *seasonally* forecast



Consequently, a potential means for forecasting SLEV and WNV transmission in south Florida is available